

CMMI CONTRIBUTIONS TO KEY ENGINEERING AREAS

“My experience has been that creating a compelling new technology is so much harder than you think it will be that you're almost dead when you get to the other shore.” Steve Jobs

CMMI plays an important role in the five ENG key areas in research and education for 2007–2008, and is leading ENG activities in simulation-based engineering and science. The following is a summary of these contributions.

Innovation

CMMI is uniquely positioned to have a significant impact on supporting research that strengthens engineers' abilities to conceptualize and create innovative products and services. The combination of program areas, spanning the scale from nanotechnology to earthquakes, materials design to hazard mitigation, and product design to infrastructure systems management, provides an environment for collaboration that supports innovative solutions to emerging problems and worldwide economic challenges.

When faced with complex situations, such as Hurricane Katrina and the clean-up and rebuilding of New York after September 11, the public looks to engineers for technical solutions. Innovative solutions are needed to solve the complex problems of aging infrastructure and maintaining our leadership in new product development. CMMI supports research that has a direct impact on how to handle extreme situations and disasters, that creates new materials and processes, and that helps in conceptualizing and producing new products.

NEXT PARADIGM SHIFT IN MANUFACTURING

CMMI supports the ENG initiative in manufacturing through the activities of several programs. The CMMI NanoManufacturing program supports research on manipulation of matter at the atomic and molecular scales and on the incorporation of nanoscale elements into larger systems to exploit their functionality. The division also supports nanomaterials research through the Materials Processing and Manufacturing program.

Multiscale modeling is supported through the Mechanics and Structure of Materials program and the Manufacturing Machines and Equipment program.

Research on information technology as it relates to manufacturing is supported in several programs.

Additionally, the Division represents NSF in the Interagency Working Group on Manufacturing Research and Development.

CMMI aims to promote a paradigm shift in manufacturing technology. This shift will come about as products are made of new materials, and as the processing of materials

becomes more advanced through new methods in machining, forming, joining, finishing, assembling and quality control. A significant research thrust is the improvement of manufacturing processes via the implementation of advanced sensors and control theory. Coupled with an improving understanding of the physics of manufacturing processes, advanced controls offer the possibility of assembly that is more accurate and efficient. They could also improve quality control and lessen the environmental impact of the manufacturing process overall.

ENERGY AND ENVIRONMENT

CMMI supports the development of a novel and diverse energy infrastructure. New manufacturing and materials processing technologies can enable the cost-effective scale-up of fundamental breakthroughs in energy harvesting and production. A key example is the manufacture of large-area solar modules based on nano-structured materials. CMMI supports fundamental research in self-assembly, continuous reel-to-reel processing of amorphous silicon laminates, and casting fuel-cell module supports in high volume as crucial techniques for improving energy producing systems.

CMMI will continue to invest in the fundamental research to improve the cost, sustainability and security of the global energy system. Research in the design and engineering of enterprise systems and the built environment to lower environmental impact is a strategic priority of CMMI. The behavior of existing material-use systems, their impact on the environment and their interaction with social processes has been a major initiative in CMMI. This initiative supports the priority of developing a system-level quantitative understanding of materials-energy-environment interactions and the impact of these systems on society.

NEW FRONTIERS IN NANOTECHNOLOGY

CMMI proactively is supporting and aligning with the national priority research area of nanotechnology, under the National Nanotechnology Initiative. CMMI (through its antecedents CMS and DMI) has established two new programs specific to nanotechnology support: the NanoManufacturing Program (established in fiscal year 2001) and the Nano- and Bio-Mechanics Program (established in fiscal year 2005). Through these and other CMMI programs, the division significantly has leveraged funding for the NSF-wide Nanoscale Science and Engineering initiative (NSE), through awards to Nanoscale Science and Engineering Centers (NSEC), Nanoscale Interdisciplinary Research Teams (NIRT) and Nanoscale Exploratory Research (NER) as well as core program awards in nanotechnology research.

CMMI has leveraged its resources to support nanoscale education via funding for various Nanoscale Science and Engineering Education (NSEE) awards, including the Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) at Northwestern University.

In fiscal year 2006, CMMI predecessor divisions contributed core funds of \$16.5 million

to the \$9.96 million NSE contribution, for a total of \$26.46 million in CMMI-related nanotechnology awards. The division manages more than 160 active nanotechnology awards, including four large-scale cooperative agreements to NSECs (at UCLA, University of Illinois at Urbana-Champaign, UC Berkeley and the University of Massachusetts Amherst). Nanotechnology research areas of CMMI awards include nanoscale surface and interfacial phenomena, theoretical modeling and simulation, nanostructured materials and nanoscale processes, nanomechanical devices and systems, and nanomanufacturing. Awarded projects often include understanding societal, ethical, legal, educational and human resource development aspects of these technologies. CMMI currently is spearheading new research directions in nanomechanical biomimetics, nanomanufacturing of infrastructure and biomanufacturing, congruent with the NNI Grand Challenge and CMMI NanoManufacturing program for fiscal year 2007–2008.

COMPLEX SYSTEMS

The United States faces a variety of challenges: the sustainability of many critical infrastructures such as healthcare delivery, changes in the nation's civil infrastructure, environmental challenges ranging from global warming to water resources, and safety and security challenges including threatened air travel, sea cargo, and food and water supply. There are also economic challenges. Several countries, particularly in Asia, have caught up with the United States in terms of various indices of innovation and are producing huge numbers of talented college graduates, particularly in engineering. This trend challenges both U.S. industry in terms of how to best compete and the U.S. academic community in terms of educating people with competitive knowledge and skills.

These systems—healthcare, infrastructure, environment, security, and the economy—are complex systems. They involve large numbers of interacting elements. The stakeholders are many and often have differing objectives and needs. With many stakeholders acting and reacting, the response of these systems can be unpredictable.

Similar needs also exist in finding fundamental principles stemming from quantum to nano and macro scales that are relevant to the analysis and design of novel materials, biological systems, manufacturing systems and devices and systems that will improve the quality of life for society in general. Such systems are good examples of being complex and require support for further breakthroughs.

The common aspect of these complex systems is the large number of nonlinear interactions among “components” that collectively lead to the emergence of unanticipated “complex behavior.” The current knowledge allows simulation-based investigation on complex systems, but knowledge and tools that lead to formal analysis, synthesis, optimization and design of complex systems are lacking.

Many CMMI programs are sponsoring research that will lead to better understanding of the phenomena of complexity. Several workshops and meetings coordinated by

members of the CMMI staff will lead to a coordinated investment strategy within the division and ENG that will catalyze new breakthroughs in term of new knowledge and tools built on existing knowledge, as well as in the emerging “science of complexity.”

SIMULATION-BASED ENGINEERING AND SCIENCE

CMMI is leading the ENG emphasis on simulation-based engineering science (SBES). This effort is expected to stimulate the science and education required to transform scientific and engineering research and practice through the integration of data, models, and people *via* cyberinfrastructure. It will allow for the effective use of these resources with the aid of important advances in computing power, data analyses, the evolution of the Web, and the resulting changes to the culture of science and engineering. Moreover, this shift will change engineering and science education, creating a class of engineers and scientists better able to respond to real-world problems via accurate and appropriate simulation. Currently, students may become experts in the use of simulation tools but few are able to develop and understand them.

Realization of this transformation and paradigm change requires new types of physical models beyond classic, powerful continuum models, bridging downward to small, fast molecular and nanometer scales and upward to process-scale, enterprise-scale, and global-scale systems. Finally, as predictive modeling underpins decision-making, simulation models and practice must advance from the calculation of hard numerical answers to the establishment of result probabilities and a means to use them to guide decision-making to be truly predictive. To do so, the models must change, and probability theory and decision theory must be integrated into engineering and science education and practice.

The SBE&S initiative will help initiate these changes and also complements NSF cyberinfrastructure initiatives by providing a central application of cyberinfrastructure hardware, software and network capabilities. It also builds on and extends the MPS Chemistry Division’s initiative on Cyber-Enabled Chemistry and meshes well with other NSF investments such as Cyber-enabled Discovery and Innovation (CDI), as it provides a more encompassing vision of this area’s potential with a specific application.